Plate Tectonics

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Week - 07
Lecture – 35
Orogeny and Epiorogeny- III Arc-Continent Collision

Ok friends, welcome to this class of Plate Tectonics and, today's class Ok friends, welcome to this class of Plate Tectonics and today's class we will talk about the Arc-Continent Collision. So, if you remember our earlier classes, we were talking about these orogenesis and special emphasis on this convergent boundary and the continent-continent collision. So, today we will talk about this Arc-Continent Collision. So, if you remember our earlier discussions, there are two types of arc one is called volcanic arc which is formed on this continent itself like this Andes mountain system where this Nazca plate is undergoing the South American plate. And another is the island arc mostly they occur in the ocean basin. So, once we are saying this is the continental arc or the volcanic arc that means, it is itself it is a part of this continental system.

See there is no question of collision with another continent, but once we say it is island arc system which is a part of this ocean body when the isolated mass which is occurring on the ocean body. During convergence this continental mask it is colliding with the arc system. So, in this today's class we will talk about this Arc-Continent Collision and towards the end part of this class we will talk about this epiorogeny. So, far we are discussing about this orogeny or this mountain building processes and this Arc-Continental Collision is also a part of this orogeny and after this discussion we will confine ourselves in the epiorogeny part.

So, now this orogenic belt that results from the collision between this island arc and a continent it is typically are smaller than those they are formed from this continent-continent collision. So, if you remember our earlier class when we are talking about the continental-continental collision that means it is a vast, the vast continent system they are colliding like the Indian and Eurasian system, but if you remove this Tethys ocean in between so that means simply we are colliding this Indian lithosphere with the Eurasian lithosphere or the Chinese lithosphere. But when there was Tethys ocean existing that means there was a subduction zone and due to this subduction zone there was volcanism and the volcanoes they are arranged in an arc shape and when this the end point of this closure of this Tethys ocean those arcs or these volcanoes that must have been collided with the Indian system with the Indian part and due to that reason also if you remember we were talking about this pre-collisional history of this continent due to this volcanism, due to this extension, due to metamorphism, magmatism the continental system that becomes weaker and when that is colliding with this another continental system if it is rigid like the Indian plate then the weaker section that got deformed at first and that means the mountain building processes starts. So, here we are talking about this arc-continental collision and this orogenic belt that is created by this arc and continental collision. It is relatively small because the arc cannot be as large as a continent because there are small volcanoes series of volcanoes they are arranged of different generation of volcanoes they are arranged.

So whatever may be, but number of volcanoes if they are arranged side by side they are forming the part of this continental mass within that ocean basin, but that cannot be compared to this whole that means size of a continent. So that is why this mountain building processes or this orogenic belt which are occurring due to this arc continental collision they are of smaller size compared to this orogenic belt which is formed by this continental-continental collisional system. And this arc-continental collisional system it is relatively short-lived because this arc is smaller size so it cannot collide for millions or billions of years. So just a small size material which once it is colliding with this continental mass it becomes a part of this continent and separated by a suture zone. So that is why this collisional duration that also short-lived because it is usually presented as an intermediate step during the closure of the contrasting ocean basin.

So that means here if you see this diagramically represented there is two continental system and this is subducting down and due to the subduction there will be dehydration and finally, there is the volcanoes they are occurring and this is the back-arc system back-arc spreading is there back-arc basin some sediments are deposited in the back-arc basin system. Now once this continent is moving this way and this whole lithosphere which is of oceanic origin it was consumed that means this arc system it is colliding with the continental system. In the next figure if you see this whole oceanic system is consumed now this continent and this continent they are colliding they are close to each other and in between this arc which was formed by this volcanoes they are remaining here. So that means once it is happening so and suppose there is ocean basin still existing suppose this merging or the merger of this volcanic arc or this island arc system within the continent still this part we have some ocean basin. So what is happening there? So once it is ocean basin is there and this total system is consumed but still they are colliding with each other so finally, this ocean basin which was existing here that may subduct here.

So that means the polarity of the subduction may changes with time. The best example of this arc-continental collision is the Taiwan, Papua New Guinea and this Timor-Banda Arc region of Australia. Here you see this diagrammatically represented this is the Australian shield which is subducting here beneath the Eurasian system and here this is the fore-accretion region and this is the Timor arc which is attaching with this crystalline basement of this Australian shield. So now it becomes a part of this continental system earlier it was representing an island but this ocean segment in between it was consumed so that this island system it is colliding with this crystalline basement of the Australian system and becomes part of it. So this is the arc-continent collisional system and these collisional system provide important information on the mechanism of this continental growth by terrane accretion.

So terrane accretion if you probably you can remember when we were talking about the growth of this continent for Precambrian time up to recent. So this accretion term had been used there are two types of accretion one is vertical accretion which is due to this radiation of heat from this crustal mass or the lower part of the crust or the upper part of this mantle that become welded with the lower part of the crust. So gradually the thickness of this crust increased that is called vertical accretion because there is a vertical growth increase of thickness z dimension. But there are another accretion that discussed that is called lateral accretion. So this lateral accretion is nothing this is the terrane accretion.

So terrane this term terrane it is composed of different litho units like igneous terrane, metamorphic terrane, sedimentary terrane. So now if you see here we have two continental system that is continental terrane or this igneous or metamorphic terrane. Now we have magmatic activity that means we have igneous terrane here then once it is a basin we have sedimentary bodies so sedimentary terrane. So different terrains they are accreted that means added welded together and forming this mass of this continent and become this part of this continent. So that is why it is called terrane accretion these are the mechanism how the terrains are accreted and become this part of this continent.

As the island arc approaches a continent by the consumption of an intervening ocean collision begins when this continental margin is driving below the inner wall of the trench and the system is choked. So here this positive buoyancy of this continental lithosphere slows the rate of underthrusting and it may lock the trench. So now if you see so this is the system which is going down and once this oceanic lithosphere it totally consumed so this continent of this and continent of this part they are coming close to each other and none of this continental mass that will move down because this there is a very high density contrast with this mantle. So that only collision occurs and this part as it was attached with the ocean body so oceanic lithosphere part of this part will subduct down but not further more because the density contrast is there. So this mantle will push it up so that it will choke this trench system and finally it is locked and due to this locking this collision starts.

If the continental margin is irregular or lies at an angle with respect to this island arc the timing of arc-continent collision may vary and along the strike. So this is best exemplified by this is the Timor-Banda arc in Taiwan. Now you see this continental margin of this Australian subcontinent it is different and this is this Chinese part this is the Eurasian system this continental margin also irregular. So what is happening here this collision is occurring here however this distance is remaining. So that means some part it will experience the collisional mountain system and some part it will experience subduction system.

So that is why if this continental margin is irregular partly it may represent the collisional system and partly it will represent the subduction system. So that is why the timing varies timing of collision varies because here the timing will be different here the timing will be different because this much distance is to be covered and this much distance of the ocean body is to be consumed. But here we have consumed all this ocean body only the continent-continent collision is going to occur or this arc-continent collision is going to occur. However here the whole segment of this ocean has to be consumed that means it is a time taking process. So, it is only happens when there is a irregular continental boundary that means you can see here this is best example of this Timor-Banda arc.

As the collision begins the forearc region and this accretionary wedge are uplifted and deformed as a thrust and faults carrying slice of the flysch and other continental crusts and to this continental plate. So what does it mean? Now you see here these two diagrams can explain you better way. So we have a ocean body which was subducting down and these are the arcs and here we have this forearc basin and we have put some sediment here that is the sedimentary basins are here and due to this collision here you see this is compressional environment and due to compressional environment we will create some fold and then we have some thrusts. So, due to thrusting slice of this continental arc and slice of this volcanic arc and slices from this intervening sedimentary system they are migrating to large distance and due to this migration here so this continental accretion takes place. If the two plates that continue to converge a new trench may develop on this oceanward or the backside of this island arc system.

So, that can be well explained here by this figure. So, imagine earlier this plate was subducting down this is the continental system having some ocean body and here this much is the ocean and this is the back-arc basin this side is the back-arc basin this is another ocean body back-arc spreading is occurring here. Now we have consumed the whole oceanic lithosphere from here. So, once we consumed the whole oceanic lithosphere this continental lithosphere is coming in contact with this arc system and once they are coming with the arc system, but still compression is going on from both sides. So, that these two continental systems they welded together and forming a continental mass which is becomes a part of this continent here, but still the ocean body is remaining and the compression is going on.

So, one side is ocean basin another side is the continental system. So, once the compression is going on being the ocean basin heavy so, it will move down. So, that means, now you see earlier this subduction was going on and the subducting plate was from this side, but now the subducting is plate is from this side. So, this polarity of the subduction is changing and this is here this Timor-Banda arc region is an example of this arc-continental collision and this overlapping or this change of this polarity of the subduction system. So, that can be explained here with geological time.

Prior to 3 million years oceanic lithosphere of this Indo-Australian plate it was subducted northward beneath the Eurasian plate at the Java Trench. Here you can see this is the Java Trench and this is the Indo-Australian plate it was subducting down if you see here this is the subduction zone, this is the triangle which is indicating the abducting plate, this is the abducting system and this was the subducting down. And after that what happened this subduction created Banda volcanic arc and is a north dipping Benioff zone that extends up to a depth of 700 kilometer. This is the deepest subduction zone that is 700 kilometer that has been reported here. So, now if you see here this one it was subducting northward and we have a subduction zone which is dipping towards north.

But after that what is happening here between 3 million years to 2 million years subduction brought the Australian continental lithosphere in contact with this Banda forearc and part of which is thrust southward over the colliding Australian continental margin. So, now you see this is the Banda system this is the Banda-Timor system. So, due to this irregular geometry of this continental margin, so this Banda-Timor system it is thrusted upon this continental system and become part of this continent. So, here once this becomes a part of this continent that means, here this continental-continental collision is going on. So, what is this result of that? So, this down going Australian continental slope choked the subduction zone and is a created a fold and thrust belt that has been deformed both the forearc sequences and structurally lower unsubducted cover sequence of this Australian continental margin.

Within the adjacent volcanic arc north of Timor, volcanism has been stopped. So, now you see once there is a continental-continental collision, so those arcs which are formed like Wetar, Alor where this volcanism has been stopped. So, once the volcanism has been stopped, so that means, but at the same time this side that means the western side it is still going on. So, that is why west side the tectonic collisional zone volcanism is still occurring on the islands of the Flores, that is Sumbawa and Lombok, north of this triangular Savu-wetar forearc region. So, here due to its irregular geometry we are experiencing this arc-continental collision here.

Once arc-continental collision is there that means, the system is choked the trench is choked, so no more subduction. So, this side the subduction is going on, as this side is subduction is going on, so there is Benioff zone existing, so that volcanoes are active, but this side the volcanoes become extinct. And seismicity pattern provides the evidence of a past northward subduction of this Indian oceanic lithosphere beneath the Banda Sea at the Banda Trench. And this continuation of this Java Trench is the Banda Trench before it was obliterated by its collision with the Australian continental lithosphere. And earthquake hypocenters beneath the Wetar strait and Banda arc marks suggest the descending continental lithosphere to below about 300 kilometer.

So that means, earlier it was existing here, now this continental lithosphere it is somehow it is subducting, but it could not more than that so it will come back like this. So, that is why this Banda-Timor system it becomes a part of this continental system and if more islands are existing that will also collide with the system and becomes a part of this continental system zone. So, now this is the seismic profile, it says how this lithosphere was subducting earlier because this is the across, this is A which is across you see this is the across system and it was saying how this Australian Indo-Australian lithosphere it was subducting below this Eurasian lithospheric system. And this tomographic image of the Banda slab vertical section through this tomography model along and across the Timor arc says this system was subducting earlier, but now it is representing this arc-continent collision zone. And the earthquake record suggests that the upper and the lower part of the subduction zone of the Timor region is now locked.

So, once it is locked that means, no more seismicity inside, but once it is subducting down that is the western part this side the seismicity is there and Benioff zone is existing, but here no more Benioff zone is existing nowadays. So, north of this Banda arc two north directed thrust faults has been developed. Now if you can see here we have north direction that means, two thrust has been developed, one is Flores thrust another is the Wetar thrust and these thrust are nothing these are the indicator of the subduction. So, that means, earlier the subduction was from this side here, but now the subduction is this side. Similarly, if you see earlier this thrust was up to dipping towards north now the thrust they are dipping towards south.

So, north dipping thrust was there now south dipping thrust is there. So, in between this is the Banda-Timor arc which is welded with the Australian system and in future there will be subduction zone here there will be subduction zone. So, whatever this oceanic lithosphere is remaining here that will subduct down along this Australian system or below the Australian shield. Now terrane accretion and continental growth whatever we have discussed so far this continental arc collision continental continental collision and this subduction system. So, all this system it says there is accretionary system in the terranes.

So, many orogens are composed of a collage of fault-bounded blocks that preserve geologic history underlying to those of this adjacent rocks. So, here you can see different thrust sheets of different origin that means, originated from different depth they are migrating due to this collisional system and they are welding the different rock types generated different depth together. And this is called this terrane accretion and this terrane accretion is a prominent region for this continental growth. So, these units are known as terranes and may range in size from few hundreds to thousands of square kilometer. Terranes usually are classified into groups according to whether they are native or exotic and their adjacent continent and craton.

So, this exotic terranes generally they are derived from large distance. For example, Himalayan thrust sheets this migration is large distance that the exotic terranes and native terranes that means, inside to terranes which are just exhumed and coming from those original places. So, exotic or the allochthonous terranes are those that have moved relative to the adjacent bodies and in some cases have travelled very great distance. The boundaries of the terrane may be normal, reverse or strike-slip fault occasionally they may preserve thin ophiolites, blueschists or highly deformed flysch. So, this ophiolite, blueschists and highly deformed flysch that depends upon which portions this slice has been segmented and it is been migrated.

If it is coming from this continental-continental collision zone or it is coming from this subduction zone where this oceanic lithosphere and this continental lithosphere they are in contact with so, that is the blueschist system. And if it is ophiolite that means, it is the oceanic part and it is flysch sediments that is the back-arc basin or the forearc basin sediments. So, that means, now you see we have ophiolites that means, it is a basaltic rock or this total lithosphere oceanic lithosphere and we have blueschist facies that is the oceanic lithosphere which is totally metamorphosed. Then we have sediments so, that origin is different. Now due to this continental accretion due to this arc accretion so, this differently originated bodies of terranes they are close to each other and forming this part of this continent.

If you see here this color code that indicates how these terranes are aggregated and due to this deformation due to this collision now they are welded together and they can be easily identified by field work through the presence of suture zones. And the differentiation and the analysis of terranes is one of the most useful approaches to determine this longterm evolution of the orogens, the mechanism of this continental growth and the origin of this constituent components of this continental lithosphere. So, where this terrane is coming and what is the nature of this terrane? So, from what depth it has exhumed to what extent that has been deformed and what is the role of this compressional tectonics in taking these terranes together that can be studied best studied in the field as well as some other proxies like isotropic analysis like metamorphic analysis like mineral analysis so, that can be studied through this. So, terranes recognition is based on the contrast in the detailed stratigraphic and structural histories although in many cases these have been destroyed and modified by the younger events because once there is deformation that is not only the one phase of deformation is undergone there are number of phases of deformation that are superimposed. So, once they are superimposed that means, the earlier evidences gradually wipes out.

So, that is why superimposition of subsequent deformation features they also obliterated this earlier signatures that was evident of this terrane accretion. So, during field work we have to process about that which type of terrane we are working, what is the degree of deformation to that and how we will distinguish from one deformation event to another deformation event. So, if we can establish the different deformation events then we can say the history of terrane accretion with time. The original nature of this bounding faults of many terranes may be obscured by the metamorphism, by igneous activities and by deformation that we have discussed. And igneous activities also another thing because once there is a compressional zone there will be melting, there will be temperature, there will be hydrothermal fluid, there will be magmatism.

So, through this boundaries terrane boundaries they are destroys. Therefore, in order to determine whether the geological history of the adjacent terranes are compatible with their present spatial relationship very detailed and comprehensive structural, geochemical and isotopic investigations are necessary. So, that means, we need to use these proxies addition to this structural analysis from the field and laboratory. So, except field work we have to add these proxies to investigate the terrane accretion. The timing that is the dating techniques, then this isotopic techniques, the geochemical analysis all these are the proxies for the timing and the processes responsible for the terrane acceration.

Several criteria are used to distinguish the identity of the terranes. The first is the provenance and sedimentary histories and stratigraphy. Provenance we know the source identifying the source of the sedimentation, then the sedimentary history, then the stratigraphy history. So, this can be used to define a terrane. Another it is the petrogenetic affinity of the history of magmatism and metamorphism.

This is another way how the terranes can be distinguished. What is the degree of metamorphism from one region to another region? So, if it is low degree metamorphic rock it is juxtaposed with high degree of metamorphic rocks. So, that is representing two different terrane. The nature, history and style of deformation. So, the style of deformation that means, somewhere it is extensional deformation, somewhere it is compressional deformation.

So, different deformation styles somewhere it is folded, somewhere it is thrusted, faulted. So, like that joints are highly spaced there will be no joint. So, like that. So, nature, history and style of deformation.

Then paleontological history and environment. paleontologically that means, the fossil content and particularly this paleontological history it is for this sedimentary rocks exclusively because metamorphic and igneous rock they do not contain paleontology so, this paleontological history that can be used to distinguish different sedimentary terranes. Then paleopole position and paleodeclination. So, paleopole position if you remember earlier class when we were talking about polar wandering curve. So, the paleopole position that can be distinguished that can be used to distinguish the different terranes at different points. Then another is called epeiorogeny so, we have completed the orogenic part.

So, to now we will talk about epeiorogeny. Epeiorogeny this name itself says there is epi, epi means top. So, it is a vertical movement. So, the orogenic process that is movement is vertically because so far we have discussed about this compression, this is collision, this is subduction, this is divergence like that. So, this is the vertical movement rather than lateral movement. So, this epeiorogeny is nothing, it is a gradual downward or upward.

So, that means, either it is moving up or it is moving down. So, upliftment or subsidence. So, either of this case this continental crust that is moving upward or downward vertically. So, this upward or downward movement of this broad region of the crust without significant folding and faulting. Significant folding and faulting will not be associated with it, only movement vertically or subsidence vertically.

So, upheavals or depressions of land exhibiting long wavelengths and little folding apart from broad undulations. If you see here two figures are depicting the same. One is the mantle plume we are putting here. So, due to this mantle plume due to high heat there will be buoyancy force and this there will be a large curved part of this earth large curvature that will be uplifted. Similarly if there is a rifting earlier there is a block and finally, it is started rifting.

So, that means, gradually it will create a depression of larger wavelength. So, subsequently it will convert it to a ocean basin. So, this subsidence and this upliftment it is occurring without this major folding and faulting events. So, this process comes under this epeiorogenic movement. So, the movement may be one of subsidence towards or of uplift from the center of this earth.

Either it is moving up or moving down and the movement is caused by a set of forces acting along an earth radius such as those contributing to isostasy and faulting in the lithosphere. Isostasy we know this is the state of same stress that is at certain distance from the surface of this earth. It is representing the isostasy, isos means same stress means pressure. So, same pressure it is exacting the earth different columns they are putting same pressure after certain distance and that distance is called equilibrium line. So, after that equilibrium zone that will all these earth blocks they are putting similar pressure on this mantle so, this is called isostasy.

And another is faulting due to faulting there will be vertical movement, there will be graben, there will be horst like that. So, due to faulting, due to isostasy one particular block that may move upward then may move downward. So, reason for this vertical movement may be glacial rebound because if you remember that a glacial rebound is one of the reason for isostatic imbalance. So, during glacial period this there was glaciation.

So, huge amount of water it was glaciated and putting the glacial columns, glacial sheets and this glacial sheet they are putting pressure on this earth crust.

So, the system was bending downward. So, once there is interglacial period. So, this glacier was melting. So, this pressure was unloading gradually, but still it could not retain its original position. So, the depressions are lying. So, one is the glacial rebound, another is the heating of the lithosphere from below.

So, that means, mantle plume system we have heating we are heating this lithosphere from below due to magmatic activities. Then cooling of the lithosphere in the continental interior. So, we are reducing heat, we are cooling the system that means, we are subsiding the system. Cooling this lithosphere in the continental margin, in the continental margin once we are cooling down so that means, there will be normal faulting there will be subsidence. And mantle plumes once it is occurring the mantle plume so that means, itself it is rising this continental crust above.

So, it is providing heat like this and it is itself it is as it is adding mass below this continental crust. So, this continental crust is uplifting. So, both it is responsible for heat providing and it is also responsible for mantle plumes. Both are responsible for isostatic imbalance and it is responsible for this upliftment of this earth crust.

And epeiorogenic movement can be permanent or it is a transient. So, what is transient? Transient upliftment can occur over a thermal anomaly due to convecting anomalously hot mantle and disappears when convection wanes out. So, that means, here this is temporary, but sometimes it is becomes permanent. Permanent upliftment can occur when igneous material is injected that means, the mantle plume it is coming out and it is injected below. So, once it is injected below this part of this crust is curving out. So, that is it is the permanent uplift that can occur when the igneous material is injected into the crust and circular or elliptical structural uplift over a large radius is one characteristics of this mantle plume.

So, either of this case it is moving up or moving down. If without much deformation vertical upliftment or subsidence is occurring that is coming under this epeiorogenic system. So, here some of the reason that we have discussed so far we have rifting, rift section this is subsidence, it is subsiding this large part of this crust is subsiding. Similarly this is the glacier sheet loading. So, during loading you see the crustal part it is bending down, but once it is melting this glaciers system is removed, but it is trying to rebound its position. Similarly this is the mantle plume once the mantle plume is here it is providing some space.

So, that is why to adjust this part is curving out and finally, this will create a basin. So, it will converted to this and subsequently it will convert to a ocean basin. So, these are the ways how the epeiorogenic movement can be explained. So, thank you very much we will meet in the next class.